THE "PAUSE" IN GLOBAL WARMING

Turning a Routine Fluctuation into a Problem for Science

BY STEPHAN LEWANDOWSKY, JAMES S. RISBEY, AND NAOMI ORESKES

Contrarian discourse about a "pause" in global warming has found traction in climate science even though there is little evidence for anything but a fluctuation in the warming rate similar to earlier deviations from a longer-term trend.

Many indicators confirm that Earth continues to warm from greenhouse gases (Abraham et al. 2013; Balmaseda et al. 2013; Durack et al. 2014). Notwithstanding, climate contrarians have been claiming for nearly a decade that global warming has "stopped" (Carter 2006). Boykoff (2014) showed how, over time, those repeated contrarian claims entered the discourse in the media and among policy makers and politicians. In consequence, climate change has frequently been framed around the presumed fact that global warming—measured by global mean surface temperature (GMST)—has "stalled," "stopped," "paused," or entered a "hiatus." Evidence for the widespread adoption of this frame is provided by a *Google Trends* analysis (conducted on 21 October 2014), which reveals that the search term "global warming stopped" has been used nearly continuously since February 2008, with distinct spikes ahead of the climate meetings in Copenhagen, Denmark (December 2009), and Doha, Qatar (November 2012).

This frame has also found explicit uptake in the peer-reviewed literature, with two special issues of *Nature* journals devoted to the "pause" or "hiatus" in early 2014, and a total of more than 40 articles having appeared in print on the pause by 2014. Moreover, the Intergovernmental Panel on Climate Change (IPCC), which reflects the scientific consensus on climate change, adopted the term hiatus in its Fifth Assessment Report, and even gave it a definition "as the reduction in GMST trend during 1998–2012 as compared to the trend during 1951–2012" (IPCC 2013, Box TS.3).

Is there a meaningful pause or hiatus in global warming? If not, what has caused the scientific community to devote such intense activity to analyzing something that does not exist? This article presents

AFFILIATIONS: LEWANDOWSKY—University of Bristol, Bristol, United Kingdom, and University of Western Australia, Crawley, Western Australia, Australia; RISBEY—Oceans and Atmosphere, CSIRO, Hobart, Tasmania, Australia; ORESKES—Department of the History of Science, Harvard University, Cambridge, Massachusetts
CORRESPONDING AUTHOR: Stephan Lewandowsky, School of Experimental Psychology and Cabot Institute, University of Bristol, 12a Priory Rd., Bristol BS8 1TU, United Kingdom
E-mail: stephan.lewandowsky@bristol.ac.uk

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evidence that there has been no meaningful pause in global warming and offers an account of why this notion has become so widespread in the scientific community.

There has been ongoing analysis and commentary arguing against the existence of a statistically meaningful pause for several years (e.g., Foster and Rahmstorf 2011). Two analyses of the GMST time series have failed to find any statistical evidence for a slowdown (Foster and Abraham 2015), or a distinct changepoint in the rate of warming (Cahill et al. 2015). There have also been questions about biases in some datasets used to identify a potential pause (Cowtan and Way 2014; Karl et al. 2015). Most recently, a bias-corrected release of the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) dataset (Karl et al. 2015) assessed the rate of warming during the hiatus period identified by the Intergovernmental Panel on Climate Change (IPCC; 1998–2012) to differ little from the longer-term trend considered by the IPCC for comparison (1951–2012). Although those bias corrections were unavailable at the time when the pause gained entry into the literature, we show below that our conclusions do not depend on those corrections.

Accordingly, there are other indications of longstanding disquiet with the presumed pause. For example, the IPCC's use of the term hiatus (without scare quotes) came under critical scrutiny during review of the Fifth Assessment Report. In a high-priority comment on the Summary for Policy Makers, the German government noted that the term hiatus was strongly misleading and recommended against its use.[1] Although the German delegation's suggestion was not adopted, it points to a fundamental problem surrounding the pause: what exactly is meant by a pause or hiatus?

WHAT IS A PAUSE? By definition, a "pause" involves the interruption or suspension of a process. The presence of a pause or hiatus in global warming would thus mean what contrarians say it means (e.g., Carter 2006), namely, that warming had stopped, at least for a time. Determining whether warming has stopped is nontrivial because greenhouse-driven global warming is expressed on multidecadal and longer time scales (i.e., 30 yr and longer), whereas on shorter time scales (10–20 yr) the rate of warming speeds up and slows down relative to the longer-term average trend (IPCC 1996; Risbey 2015). At one point or another, there may therefore be periods of limited duration during which surface temperatures do not increase significantly.

In this article, we consider the period since 1970 to provide a representation of the "longer term" rate of greenhouse warming that is characteristic of the modern period. The choice of period marking the longer-term trend is necessarily somewhat arbitrary. The year 1970 has been statistically identified as an approximate marker of an upsurge in the rate of global warming on multidecadal time scales (Cahill et al. 2015). This longer-term trend (1970–2014) has been estimated at 0.17 K decade^{-1} (Cowtan and Way 2014; Karl et al. 2015) or 0.16 K decade^{-1} [National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies Surface (GISS) Temperature Analysis (GISTEMP; Hansen et al. 2010) and the Met Office's Hadley Centre/Climatic Research Unit, version 4 (HadCRUT4; Morice et al. 2012)].

By contrast, we refer to decadal scale (10–20 yr) variations in the rate of warming about a longer-term trend as *fluctuations*. Here, we focus on 15-yr trends to reflect the duration of the presumed hiatus employed by the IPCC (2013, Box TS.3). Those fluctuations may be driven by internal variability (ocean circulation and its coupling to the atmosphere), or they may involve variations in external forcings of the climate system (such as solar irradiance and aerosol concentrations), or both. These fluctuations are "routine" in the sense that they occur commonly and are caused by different combinations of the same set of processes.

A given fluctuation is defined by a start year and an end year, and its magnitude is highly dependent on the choice of start and end years. For example, the decadal rate of warming during the 15 yr centered around 2005 was 0.11 K; for the 15 yr centered on 1999 it was 0.31 K—a nearly threefold difference resulting from a shift of the temporal window by 6 yr [data from Cowtan and Way (2014)]. Fluctuations can therefore display warming rates that are greater than or less than the greenhouse-driven longer-term

[1] The full comment reads as follows: "the underlying report and the TS label the recent reduction in surface warming as 'hiatus'. The web site http://thesaurus.com gives as definition of this expression 'pause, interruption', www.merriam-webster.com gives '1a: a break in or as if in a material object, 2a: an interruption in time or continuity; break; especially: a period when something (as a program or activity) is suspended or interrupted.' All these definitions do not appropriately describe the recent temperature evolution as there is not a pause or interruption, but a decrease in the warming trend, and the first decade of this century has been the warmest since preindustrial times, see Figure SPM1. (a), lower figure. Hence, the expression 'hiatus' is strongly misleading and should not be used throughout the report" (www.climatechange2013.org/images/report/WGIAR5_FGD_FinalDraftSPMComments.pdf).

trend. There may also be short-term periods of cooling embedded within a longer-term warming trend (Easterling and Wehner 2009).

Any claims of a pause or hiatus in the recent rate of warming must therefore be assessed against the overall pattern of fluctuations in the temperature record. A claim to find a pause or hiatus is a different assertion than a fluctuation and implies that the fluctuation is extraordinary in a particular way: the meaning of the terms pause and hiatus implies that the normal fluctuations in warming rate have been surpassed such that warming has stopped. We next show that no such stoppage has occurred.

GLOBAL WARMING CONTINUES: THE STATISTICAL EVIDENCE. Detailed analyses of temperature trends have been reported previously (Easterling and Wehner 2009; Santer et al. 2011; Karl et al. 2015). Here, we generalize and update those results. The top panel in Fig. 1 shows all possible 15-yr trends in GMST for the period 1970–2014 (i.e., 1970–84, 1971–85, and so on; $N = 31$) for four different datasets. It is clear that the short-term trend sometimes falls above the longer-term trend (indicated by the gray band) and sometimes below it. It is also clear that warming has continued throughout the 45 yr as none of the trends are zero (dashed horizontal line).

The linear trend in GMST (established by ordinary least squares on annual global means) is statistically significant for the last 15-yr period (ending in 2014) for three of the four available datasets: GISS (trend, $b = 0.08$ K decade^{-1}; test statistic, $t = 2.20$; level of significance, $p < 0.05$), the dataset of Cowtan and Way ($b = 0.10$ K decade^{-1}, $t = 2.41$, $p < 0.05$), and the most recent NOAA dataset by Karl et al. ($b = 0.11$ K decade^{-1}, $t = 3.25$, $p < 0.007$). Only HadCRUT4, which does not cover parts of the Arctic where warming is known to be most rapid, fails to yield a significant trend for this 15-yr period ($b = 0.07$ K decade^{-1}, $t = 1.70$, $p > 0.10$). When a further year is included in the analysis, HadCRUT4, too, yields a significant trend ($b = 0.09$ K decade^{-1}, $t = 2.48$, $p < 0.03$).

Although the most recent 15-yr trend is significant for most datasets, there have been six occasions since 1970 when a 15-yr trend would have failed to reach significance (using GISS); namely, in the years 1986, 1993, 1994, 1995, 2011, and 2012. At all those times, the preceding 15 yr failed to show significant warming. And at all those times, the inclusion of further years renders the trend significant. The claim that global warming uniquely "stopped" during any recent 15-yr period is therefore not sustainable. Conversely, any argument about a pause, hiatus, or stoppage could have been made with equal justification (or lack thereof) repeatedly during the past 45 yr.

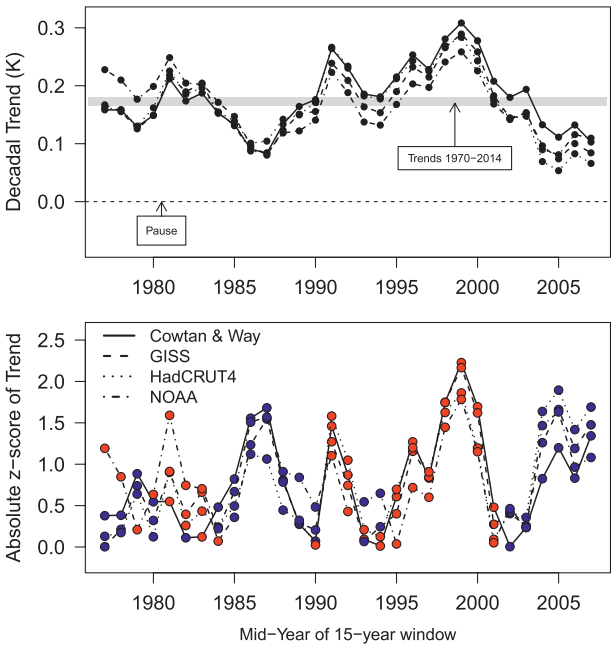

Fig. 1. Summary of all possible 15-yr trends in GMST between 1970 and 2014 inclusive. (top) The trend (K decade^{-1}) for the 15-yr window centered on the plotted year for four datasets: NASA's GISS (Hansen et al. 2010; http://data.giss.nasa.gov/gistemp/, accessed 17 Jan 2015), the Met Office's HadCRUT4 (Morice et al. 2012; www.metoffice.gov.uk/hadobs/hadcrut4/data/current/time_series/HadCRUT.4.3.0.0.annual_ns_avg.txt, accessed 2 Feb 2015), the coverage-bias-corrected version of HadCRUT4 reported by Cowtan and Way (2014) (http://www-users.york.ac.uk/~kdc3/papers/coverage2013/series.html, accessed 2 Feb 2015), and the latest NOAA dataset (Karl et al. 2015; www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/12/1880-2014.csv, accessed 12 Aug 2015). The GISS dataset is based on sea surface temperature data [Extended Reconstructed SST version 3b (ERSSTv3b)]. The decadal temperature increase is greater than zero (dashed horizontal line) in all datasets at all times. The gray horizontal band represents the average of the trends between 1970 and 2014 across the four datasets. The longer-term trend is represented as a band to capture some of the uncertainty from dataset to dataset, but also to indicate that this is an inherently imprecise quantity because it varies with the exact period that is chosen to represent a longer-term trend. (bottom) The same data as in the top panel, but 15-yr trends are converted into absolute z scores, by expressing each observed trend as the absolute difference in standard deviation units from the mean of all trends since 1970. Originally positive z scores (representing greater than average warming) are plotted in red, and originally negative z scores are shown in blue.

Nor does the most recent fluctuation constitute a uniquely large deviation from the longer-term trend.

This is shown in the bottom panel of Fig. 1, which plots the same 15-yr trends but converted into absolute z scores. The advantage of z scores is that they reexpress each data point as a deviation from the overall mean of a sample in units of standard deviation, thereby providing an indication of the extremity of the observations. To compute z scores, the mean of all possible trends was first subtracted from each individual trend, and each such difference was in turn divided by the standard deviation of all trends. To permit a comparison of decelerating ($z < 0$) and accelerating ($z > 0$) fluctuations, the z scores were converted to absolute values for plotting. For clarity, z scores that were originally negative are plotted in blue in Fig. 1, and those that were originally positive are shown in red.

For a pause to be distinctive, it must deviate below the longer-term trend more than previous periods deviated *above* the longer-term trend; otherwise, it can be considered to be just a fluctuation like others observed in the past. The bottom panel in Fig. 1 shows that this criterion for distinctiveness is not met: for all datasets bar HadCRUT4, the pause is less anomalous than the accelerated period of warming that took place during the 15 yr spanning 1999 (i.e., 1992–2006). That is, the absolute magnitudes of the z scores associated with the recent deceleration (whichever recent year is picked as the point on which the pause is centered) are consistently smaller—sometimes by a considerable margin—than those for the 1999 acceleration. Only for HadCRUT4, and only for the 15-yr period centered on 2005, are the z scores for the pause and the maximum warming virtually indistinguishable (1.86 vs –1.90).

Taken together, the statistical evidence presented here and elsewhere (Cahill et al. 2015; Foster and Abraham 2015) shows that the pause period is comparable in statistical terms with other recent fluctuations. Any exceedance of the z score of the pause period compared to other fluctuations, if it exists, is marginal and depends on the details of which dataset is used and precisely what time window is used to assess the pause. The pause is not unusual or extraordinary relative to other fluctuations and it does not stand out in any meaningful statistical sense.

Note that these conclusions are not dependent on the choice of baselines used to represent longer-term greenhouse warming. For example, a longer baseline such as the IPCC's 1951–2012 period yields a lower longer-term trend, thus rendering any fluctuations with slower rates of warming even less unusual. Our conclusions are also qualitatively unaffected by the modeling of autocorrelations and by the choice of window size for the short-term trend.

We next show that experts fail to detect evidence for a pause in a blind test.

GLOBAL WARMING CONTINUES: THE BLIND EXPERT TEST. The forecasting of time series data is central not only to climatology, but also to economics, finance, and allied disciplines. Forecasting techniques have therefore attracted considerable research attention, and the last 25 years have seen a striking reevaluation of the role of human judgment in forecasting. Whereas human judgment used to be given little if any credence in forecasting, today it is "recognised as an indispensable component of forecasting" (Lawrence et al. 2006, p. 493).

People are known to be able to learn smooth functions with considerable precision (DeLosh et al. 1997; Lewandowsky et al. 2002). People are also able to extract information from noisy data presented in graphical form (Lewandowsky and Spence 1989). In forecasting studies, participants across a broad range of expertise are now generally thought to perform well (Harvey and Bolger 1996; Harvey et al. 1997; Du and Budescu 2007), and domain experts outperform statistical models in some circumstances (Forrest et al. 2005), although this is becoming increasingly less common in weather forecasting (Baars and Mass 2005).

Here, we are interested in human forecasting not because people's predictions might constitute a viable alternative to the projections of climate models, but because forecasting judgments reveal people's perceptions of the trend in a dataset. People's extrapolations of visually presented temperature data can therefore reveal whether people believe that global warming has stopped.

To assess the claim that global warming has indeed stopped, Lewandowsky (2011) presented naïve participants with a graph of the historical temperature record, which either identified the data as global temperatures or as a fictitious share price. Figure 2 shows the results of Lewandowsky (2011) for the condition in which the data were identified as global temperatures. Respondents clearly did not perceive a pause or hiatus in the GMST data,[2] as revealed by the fact that their extrapolations (large squared plotting symbols) had a statistically significant positive slope. Extrapolations did not differ notably from a condition (not shown in the figure) in which the stimulus data were presented as fictitious share prices. In the eyes of naïve observers, therefore, global warming has not stopped but is

[2] It must be noted that at the time of the study, the time series ended in 2009. However, at that time the idea of a pause had already been established in contrarian discourse.

set to continue. People's extrapolations were, however, conservative, falling consistently below the linear extrapolation of the long-term trend. The tendency to underestimate a long-term trend is a well-established phenomenon in judgmental forecasting known as trend damping (Harvey and Bolger 1996). This observation merits further exploration because it raises the possibility that people are overly sensitive to any slowing in warming.

This possibility was explored in a blind test involving professional economists, who were asked specifically to comment on the presence of a pause or hiatus in GMST. The sample of economists (N = 25) was tested online and was recruited by a survey firm (Qualtrics.com). All experts held at least a master's degree or a Ph.D. in economics or an allied discipline, with all but four experts reporting five or more years of professional experience. Participants were shown the GMST data through 2010, but presented as "world agricultural output" (see Fig. 3). The graph was accompanied by the following statement that experts had to evaluate in light of the plotted data: "A prominent Australian critic of conventional economics, Mr. X., publicly stated in 2006, that 'There IS a problem with the growth in world agricultural output—it stopped in 1998.' A few months ago, Mr. X. reiterated that '…there's no trend, 2010 is not significantly more productive in any way than 1998.' " This statement is an exact translation, into the economic terms of world agricultural output, of a series of public statements about the putative pause or stoppage of global warming (Carter 2006, 2011).

The experts responded to six test items, which are shown in Table 1.[3] Table 1 also shows the responses of the experts on a six-point scale that ranged from "strongly disagree" (1) to "strongly agree" (6). Any mean response above 3.5 therefore represents agreement, and any mean response below 3.5 indicates disagreement, respectively, with the test item (there was no "neutral" response category). It is clear that the experts disagreed with the invocation of a pause: experts rejected the idea that the data confirm the statement and instead find that the data contradict the statement. The experts also found the statement to be misleading and ill-informed. The experts were divided on whether or not the statement is fraudulent, although nearly ⅔ of them endorsed that possibility as well. The experts were also divided on whether the statement might be compatible with the data in a "narrow sense."

[3] The experiment involved additional statements by contrarians, pertaining to other climate variables, such as glaciers and Arctic ice, that are not relevant to the present article and are not reported here.

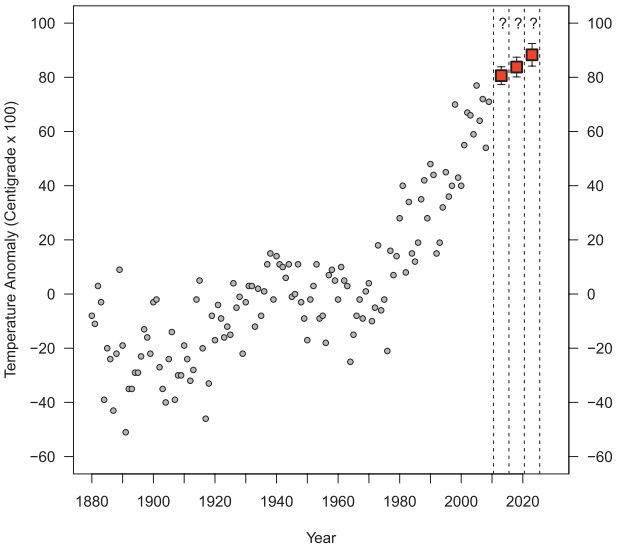

Fig. 2. Stimuli and data from an experiment by Lewandowsky (2011). Gray circles show actual global mean land surface air temperature anomalies from 1880 to 2009. Extrapolations of the trend by the respondents are represented by large red squares. When the graph was presented as a stimulus, the three questions marks (?) at the top identified the three columns in which participants marked their predictions. Temperature data are from the GISTEMP (http://data.giss.nasa.gov/gistemp/, accessed 4 Feb 2010; see also Hansen et al. 2010).

These results from our experiment are consistent with an earlier informal study conducted by the Associated Press with a small sample of statisticians who were blind to the data source (Borenstein 2009). Those experts, too, saw no evidence for a decline in the temperature trend and instead decried the cherry-picking of observations on which that claim was based.

In summary, in two blind tests, experts and novice observers alike consider the evidence of continued global warming to be clear. By contrast, statements endorsing the pause were identified by experts in forecasting and time series analysis to be misleading and at odds with the data.

WHERE DID THE PAUSE COME FROM? Our preceding analyses show that the entrenchment of the pause concept in the literature is incommensurate with the lack of evidence supporting it, and that it does not pass a blind expert test. Despite that, large segments of the climate science community, including the IPCC (2013, Box TS.3), have adopted the notion of a pause or hiatus in global warming.

This is not to say that interpretations of the pause are entirely uniform. A few articles addressing the pause question its existence. For example, Seneviratne

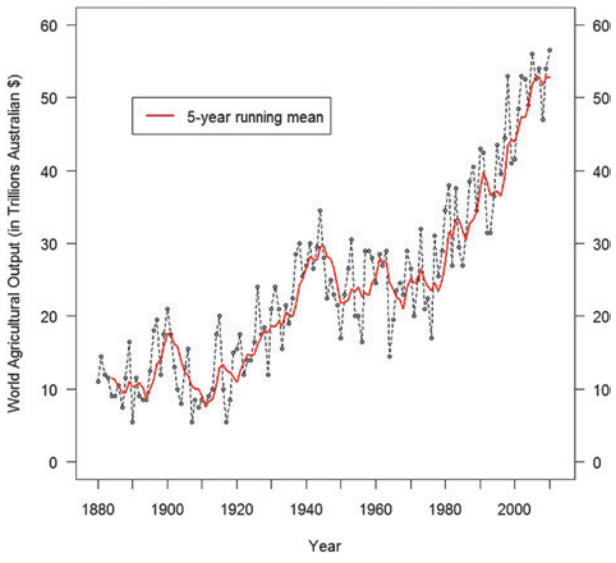

Fig. 3. Stimulus data shown to expert economists in a blind test of contrarian statements invoking the pause. See text for details. Data are actually global land–sea surface temperature anomalies from the GISTEMP dataset (http://data.giss.nasa.gov/gistemp/, accessed 3 Mar 2011; see also Hansen et al. 2010).

et al. (2014) call the term misleading and conclude that "not only is there no pause in the evolution of the warmest daily extremes over land but…they have continued unabated over the observational record" (p. 163). Risbey et al. (2014) show that recent fluctuations are not unusual and do not constitute meaningful evidence against climate model projections. Santer et al. (2014) refer to the pause or hiatus in quotation marks (i.e., scare quotes), thereby implying skepticism or disagreement with the phrase. However, the majority of the more than 40 articles on the pause that we know of start from the premise that the pause is meaningful, and present it as a significant development requiring explanation. Moreover, some researchers (albeit a minority) have taken the pause to imply that the climate system may be less sensitive to greenhouse gas emissions than previously thought (Otto et al. 2013; Curry 2014). But any use of the term—except in a clearly refutative context—is problematic because it reinforces, both in scientific and public debate, the belief that there has been a statistically meaningful cessation of warming when there has not.

How did this occur? We have shown in detail elsewhere (Lewandowsky et al. 2015) that there are several psychological and cognitive reasons why climate scientists may have been susceptible to the meme of a pause that demonstrably originated in contrarian discourse on the Internet and in the media (Boykoff 2014). Here, we suggest that a contrarian meme can find entry into the scientific community simply by exploiting scientists' commitment to explanation and to responding to intellectual challenges. Scientists generally strive to emphasize factual information and deemphasize value judgments. Indeed, "disinterestedness" has long been identified as one of the core norms of science (Merton 1942).

In a world in which contrarian claims in the media and other public arenas are overrepresented (Boykoff and Boykoff 2004; Elsasser and Dunlap 2013; Boykoff 2013), scientists may feel the need to respond to these claims. This may occur informally, as when friends, neighbors, or family members ask questions about contrarian claims they encountered online, or formally, when journalists, editors, or policy makers seek answers to contrarian talking points. If these encounters involve loaded questions, such as "What about the 'pause' in warming?," then climate scientists may inadvertently accept the biasing terms in which those questions are framed.

Frames are rhetorical and communicative structures that select and highlight certain aspects of a perceived reality over others (Dirikx and Gelders 2010). Because frames are rarely made explicit—for example, few people know that the use of the term "climate change" rather than "global warming" was advocated by Republican strategist Frank Luntz (Mooney 2005; Lakoff 2010)—frames can shape in a hidden manner the way in which people discuss an issue (de Boer et al. 2010). Would voters be more likely to support a price on carbon if it were framed as an "additional tax burden," "insurance premium for your grandchildren's well-being," or "putting a fair price on the true cost of oil and gas?" Even simple choices of wording, such as "tax" versus "offset" can have large effects on people's endorsement of policy options (Hardisty et al. 2010).

Simply by being exposed to the pause meme for over a decade, and by explaining short-term fluctuations from a longer-term trend in the terms posed to them, scientists have accepted a contrarian frame, and this acceptance may in turn have subtly changed scientists' way of thinking (Lewandowsky et al. 2015).

To illustrate, we provide citations from some recent articles on the pause in Table 2. None of those articles questioned the fundamental fact that Earth is warming from greenhouse gas emissions, and some authors even underscored the likelihood of future warming, for example by suggesting that the "present hiatus will be short-lived" with "rapid warming set to

Table 1. Test items and responses given by expert economists to contrarian statements endorsing the pause that were evaluated in light of the data.

Test item	Agreement[a]	Mean[b]	t[c]	p[d]
The data confirm the claim made by Mr. X.	0.36	2.84	−2.72	<0.02
The data contradict the claim made by Mr. X.	0.68	4.12	2.58	<0.02
The claim made about the data by Mr. X is misleading.	0.76	4.28	3.67	<0.002
The claim made about the data by Mr. X is ill-informed.	0.76	4.04	2.38	<0.03
If incompetence is ruled out, the claim made about the data by Mr. X is fraudulent.	0.64	3.84	1.49	n.s.
The statement by Mr. X is compatible with the data in a narrow sense, but the data do not support the implication of his statement, which is that world agricultural output is no longer growing.	0.52	3.60	0.34	n.s.

[a] Proportion of experts out of 25 who agreed (rating > 3) with the test item.

[b] Mean response on the six-point scale. Any value > 3.5 represents agreement.

[c] Single-sample t statistic (df = 24) comparing the mean response to the null hypothesis that the mean is equal to 3.5 (neutrality on the six-point scale).

[d] The p value of the t test in the previous column: n.s. means nonsignificant.

resume" once the present decadal variation comes to an end (England et al. 2014, p. 225). Nonetheless, the majority of articles accepted the framing of a pause and sought to explain its cause. Furthermore, the citations in Table 2—typically from the opening paragraph of an article—show that authors often framed the article by juxtaposing the continuing increase of atmospheric CO_2 levels with the presumed lack of warming on a decadal scale as though this presented a notable scientific problem at odds with expectations from greenhouse theory.

The statements in Table 2—and similar but often tacit implications of many other articles—are at variance with long-established knowledge that multidecadal natural variations in climate are superimposed on a longer-term CO_2 warming trend. These variations demonstrate that whereas CO_2 may increase year after year, surface temperature need not. More than 20 years ago, the IPCC's Second Assessment Report pointed to the importance of decadal and longer time-scale variability (IPCC 1996, 329–330), as did a U.S. National Research Council report (Martinson 1995). The IPCC summary for policy makers in the 1995 report cautioned that future decadal-scale changes would include considerable natural variability despite the longer-term warming.

If this knowledge had been foremost on scientists' minds, rather than the contrarian pause meme, the framing of many recent research articles arguably would have been different. Instead of opening an article with "Despite ongoing increases in atmospheric greenhouse gases, the Earth's global average surface air temperature has remained more or less steady since 2001," we suggest that scientists might have adopted a more appropriate framing such as "It has long been known that the longer-term greenhouse warming trend is punctuated with decadal and longer fluctuations. In this article we show that the most recent fluctuation during which warming fell below the longer-term trend was due to…"

THE MERITS OF RESEARCH ON THE PAUSE. The body of work on fluctuations in warming rate has clearly contributed to our understanding of decadal variations in climate. For example, studies have shown that the negative radiative forcing from stratospheric loadings of volcanic aerosol has increased in recent years and is larger than previously thought (Solomon et al. 2011; Neely et al. 2013; Ridley et al. 2014; Santer et al. 2014). Research has also highlighted processes whereby the ocean can vary the rate at which heat is taken up from the surface (Kosaka and Xie 2013; England et al. 2014).

Research on decadal fluctuations has also highlighted differences in expectations between climate projections that tend to average out decadal variations and the actual transient response of the climate system (Schneider and Thompson 1981) that includes such variation. Research has shown that differences in expectation between averages of projections and the actual transient response are related to model-versus-observed differences in the phasing of internal variability (Meehl and Teng 2014; Risbey et al. 2014), systematic errors in some of the external forcings used

Table 2. Representative quotations from peer-reviewed articles that frame the pause or hiatus as a problem for climate science.

Quotation	Source
"Reconstructions of global mean surface temperature [Hansen et al. 2010; Morice et al. 2012] show rising values after the 1960s but a slowing of the warming in the 2000s, even though atmospheric greenhouse gas concentrations continued to increase. This hiatus in warming may have been exaggerated by sampling errors [Cowtan and Way 2014], but a significant slowdown is evident."	(Drijfhout et al. 2014, p. 7868)
"Despite ongoing increases in atmospheric greenhouse gases, the Earth's global average surface air temperature has remained more or less steady since 2001."	(England et al. 2014, p. 222)
"The warming of the climate system is unequivocal as evidenced by an increase in global temperatures by 0.8°C over the past century. However, the attribution of the observed warming to human activities remains less clear, particularly because of the apparent slow-down in warming since the late 1990s."	(Estrada et al. 2013, p. 1050)
"Despite a sustained production of anthropogenic greenhouse gases, the Earth's mean near-surface temperature paused its rise during the 2000–2010 period."	(Guemas et al. 2013, p. 649)
"Given the widely noted increase in the warming effects of rising greenhouse gas concentrations, it has been unclear why global surface temperatures did not rise between 1998 and 2008."	(Kaufmann et al. 2011, p. 11,790)
"Despite the continued increase in atmospheric greenhouse gas concentrations, the annual-mean global temperature has not risen in the twenty-first century, challenging the prevailing view that anthropogenic forcing causes climate warming."	(Kosaka and Xie 2013, p. 403)
"Despite continued growth in atmospheric levels of greenhouse gases, global mean surface and tropospheric temperatures have shown slower warming since 1998 than previously."	(Santer et al. 2014, p. 185)
"Despite increasing radiative forcing, the observed globally averaged annual mean surface temperature (Tmean) has only increased very slowly since the late 1990s (e.g., IPCC AR5 2013)."	(Sillmann et al. 2014, p. 1)

in Coupled Model Intercomparison Project phase 5 (CMIP5) simulations (Fyfe et al. 2013; Schmidt et al. 2014), incomplete coverage and quality of observations (Karl et al. 2015), and use of incommensurate measures between models and observations (Cowtan et al. 2015).

In addition, the statistical properties of many different examples of decelerating fluctuations are very similar in observations and in models (Risbey et al. 2014; England et al. 2015; Marotzke and Forster 2015). Other research has highlighted that there will be similar fluctuations (in both directions; faster as well as slower warming) in the future, a point about which policy makers perhaps need to be reminded (Easterling and Wehner 2009; Hawkins et al. 2014; England et al. 2015).

Research on the pause has thus ultimately reaffirmed the overall reliability of climate models for projecting temperature trends. However, by accepting the framing of a recent fluctuation as a pause or hiatus, that research has, ironically and unwittingly, entrenched the notion of a pause (with all the connotations of that term) in the literature as well as in the public's mind.

PUTTING THE PAUSE TO FUTURE "PAUSES." To avoid misframing in the future does not mean that scientists should necessarily avoid an issue simply because it has gathered public prominence or is being used by contrarians. Scientists have previously responded to contrarian memes with success, for example by showing that appeals to the sun or galactic cosmic rays fail to explain global warming (Benestad 2013; Sloan and Wolfendale 2013). Concerning the recent fluctuation, we have shown that its framing as a pause or hiatus that constitutes a problem for greenhouse warming is incorrect, because it is not meaningfully different from other fluctuations in warming rate. If the fluctuation were instead framed as an instance of decadal variation, then scientists would be able to put the pause to misleading contrarian claims that global warming has stopped.

It bears remembering that the point of contrarian memes is to "keep the controversy alive" (Oreskes and Conway 2010). Accepting contrarian linguistic frames helps maintain the fiction that the science is still too uncertain to form a reliable basis for public policy. Moreover, it should be noted that the remaining uncertainties often provide a greater, rather than lesser, impetus for mitigation (Lewandowsky et al. 2014a,b).

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REFERENCES

Abraham, J. P., and Coauthors, 2013: A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change. *Rev. Geophys.*, **51**, 450–483, doi:10.1002/rog.20022.

Baars, J. A., and C. F. Mass, 2005: Performance of National Weather Service forecasts compared to operational, consensus, and weighted model output statistics. *Wea. Forecasting*, **20**, 1034–1047, doi:10.1175/WAF896.1.

Balmaseda, M. A., K. E. Trenberth, and E. Källén, 2013: Distinctive climate signals in reanalysis of global ocean heat content. *Geophys. Res. Lett.*, **40**, 1754–1759, doi:10.1002/grl.50382.

Benestad, R. E., 2013: Are there persistent physical atmospheric responses to galactic cosmic rays? *Environ. Res. Lett.*, **8**, 035049, doi:10.1088/1748-9326/8/3/035049.

Borenstein, S., 2009: Statisticians reject global cooling: Some skeptics claim Earth is cooling despite contrary data. MSNBC, accessed on 18 August 2010. [Available online at www.msnbc.msn.com/id/33482750/.]

Boykoff, M. T., 2013: Public enemy no. 1? Understanding media representations of outlier views on climate change. *Amer. Behav. Sci.*, **57**, 796–817, doi:10.1177/0002764213476846.

——, 2014: Media discourse on the climate slowdown. *Nat. Climate Change*, **4**, 156–158, doi:10.1038/nclimate2156.

——, and J. M. Boykoff, 2004: Balance as bias: Global warming and the US prestige press. *Global Environ. Change*, **14**, 125–136, doi:10.1016/j.gloenvcha.2003.10.001.

Cahill, N., S. Rahmstorf, and A. C. Parnell, 2015: Change points of global temperature. *Environ. Res. Lett.*, **10**, 084002, doi:10.1088/1748-9326/10/8/084002.

Carter, B., 2006: There IS a problem with global warming…it stopped in 1998. *The Telegraph*, accessed 18 August 2010. [Available online at www.telegraph.co.uk/comment/personal-view/3624242/There-IS-a-problem-with-global-warming…-it-stopped-in-1998.html.]

——, 2011: 2010 one of the hottest on record. ABC Australia, accessed 2 November 2014. [Available online at www.abc.net.au/am/content/2011/s3117917.htm.]

Cowtan, K., and R. G. Way, 2014: Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends. *Quart. J. Roy. Meteor. Soc.*, **140**, 1935–1944, doi:10.1002/qj.2297.

——, and Coauthors, 2015: Robust comparison of climate models with observations using blended land air and ocean sea surface temperatures. *Geophys. Res. Lett.*, **42**, 6526–6534, doi:10.1002/2015GL064888.

Curry, J., 2014: The global warming statistical meltdown. *Wall Street Journal*, accessed 2 November 2014. [Available online at http://online.wsj.com/articles/judith-curry-the-global-warming-statistical-meltdown-1412901060.]

de Boer, J., J. A. Wardekker, and J. P. van der Sluijs, 2010: Frame-based guide to situated decision-making on climate change. *Global Environ. Change*, **20**, 502–510, doi:10.1016/j.gloenvcha.2010.03.003.

DeLosh, E. L., J. R. Busemeyer, and M. A. McDaniel, 1997: Extrapolation: The sine qua non of abstraction in function learning. *J. Exp. Psychol. Learn. Mem. Cogn.*, **23**, 968–986, doi:10.1037/0278-7393.23.4.968.

Dirikx, A., and D. Gelders, 2010: To frame is to explain: A deductive frame-analysis of Dutch and French climate change coverage during the annual UN Conferences of the Parties. *Public Understanding Sci.*, **19**, 732–742, doi:10.1177/0963662509352044.

Drijfhout, S. S., A. T. Blaker, S. A. Josey, A. J. G. Nurser, B. Sinha, and M. A. Balmaseda, 2014: Surface warming hiatus caused by increased heat uptake across multiple ocean basins. *Geophys. Res. Lett.*, **41**, 7868–7874, doi:10.1002/2014GL061456.

Du, N., and D. V. Budescu, 2007: Does past volatility affect investors' price forecasts and confidence judgements? *Int. J. Forecasting*, **23**, 497–511, doi:10.1016/j.ijforecast.2007.03.003.

Durack, P. J., P. J. Gleckler, F. W. Landerer, and K. E. Taylor, 2014: Quantifying underestimates of long-term upper-ocean warming. *Nat. Climate Change*, **4**, 999–1005, doi:10.1038/nclimate2389.

Easterling, D. R., and M. F. Wehner, 2009: Is the climate warming or cooling? *Geophys. Res. Lett.*, **36**, L08706, doi:10.1029/2009GL037810.

Elsasser, S. W., and R. E. Dunlap, 2013: Leading voices in the denier choir: Conservative columnists

dismissal of global warming and denigration of climate science. *Amer. Behav. Sci.*, **57**, 754–776, doi:10.1177/0002764212469800.

England, M. H., and Coauthors, 2014: Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus. *Nat. Climate Change*, **4**, 222–227, doi:10.1038/nclimate2106.

——, J. B. Kajtar, and N. Maher, 2015: Robust warming projections despite the recent hiatus. *Nat. Climate Change*, **5**, 394–396, doi:10.1038/nclimate2575.

Estrada, F., P. Perron, and B. Martinez-Lopez, 2013: Statistically derived contributions of diverse human influences to twentieth-century temperature changes. *Nat. Geosci.*, **6**, 1050–1055, doi:10.1038/ngeo1999.

Forrest, D., J. Goddard, and R. Simmons, 2005: Odds-setters as forecasters: The case of English football. *Int. J. Forecasting*, **21**, 551–564, doi:10.1016/j.ijforecast.2005.03.003.

Foster, G., and S. Rahmstorf, 2011: Global temperature evolution 1979-2010. *Environ. Res. Lett.*, **6**, 044022, doi:10.1088/1748-9326/6/4/044022.

——, and J. Abraham, 2015: Lack of evidence for a slowdown in global temperature. *Variations*, Vol. 13, No. 3, U.S. Climate and Variability and Predictability (CLIVAR) Program, Washington, DC, 6–9. [Available online at https://usclivar.org/sites/default/files/documents/2015/Variations2015Summer.pdf.]

Fyfe, J., K. Salzen, J. Cole, N. Gillett, and J.-P. Vernier, 2013: Surface response to stratospheric aerosol changes in a coupled atmosphere–ocean model. *Geophys. Res. Lett.*, **40**, 584–588, doi:10.1002/grl.50156.

Guemas, V., F. J. Doblas-Reyes, I. Andreu-Burillo, and M. Asif, 2013: Retrospective prediction of the global warming slowdown in the past decade. *Nat. Climate Change*, **3**, 649–653, doi:10.1038/nclimate1863.

Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change. *Rev. Geophys.*, **48**, RG4004, doi:10.1029/2010RG000345.

Hardisty, D. J., E. J. Johnson, and E. U. Weber, 2010: A dirty word or a dirty world? Attribute framing, political affiliation, and query theory. *Psychol. Sci.*, **21**, 86–92, doi:10.1177/0956797609355572.

Harvey, N., and F. Bolger, 1996: Graphs versus tables: Effects of data presentation format on judgmental forecasting. *Int. J. Forecasting*, **12**, 119–137, doi:10.1016/0169-2070(95)00634-6.

——, T. Ewart, and R. West, 1997: Effects of data noise on statistical judgement. *Think. Reason.*, **3**, 111–132, doi:10.1080/135467897394383.

Hawkins, E., T. Edwards, and D. McNeall, 2014: Pause for thought. *Nat. Climate Change*, **4**, 154–156, doi:10.1038/nclimate2150.

IPCC, 1996: *Climate Change 1995: The Science of Climate Change*. Cambridge University Press, 572 pp.

——, 2013: Summary for policymakers. *Climate Change 2013: The Physical Science Basis*, T. F. Stocker et al., Eds., Cambridge University Press, 33–115.

Karl, T. R., and Coauthors, 2015: Possible artifacts of data biases in the recent global surface warming hiatus. *Science*, **348**, 1469–1472, doi:10.1126/science.aaa5632.

Kaufmann, R. K., H. Kauppi, M. L. Mann, and J. H. Stock, 2011: Reconciling anthropogenic climate change with observed temperature 1998–2008. *Proc. Natl. Acad. Sci. USA*, **108**, 11 790–11 793, doi:10.1073/pnas.1102467108.

Kosaka, Y., and S.-P. Xie, 2013: Recent global-warming hiatus tied to equatorial Pacific surface cooling. *Nature*, **501**, 403–407, doi:10.1038/nature12534.

Lakoff, G., 2010: Why it matters how we frame the environment. *Environ. Commun.*, **4**, 70–81, doi:10.1080/17524030903529749.

Lawrence, M., P. Goodwin, M. O'Connor, and D. Önkal, 2006: Judgmental forecasting: A review of progress over the last 25 years. *Int. J. Forecasting*, **22**, 493–518, doi:10.1016/j.ijforecast.2006.03.007.

Lewandowsky, S., 2011: Popular consensus: Climate change set to continue. *Psychol. Sci.*, **22**, 460–463, doi:10.1177/0956797611402515.

——, and I. Spence, 1989: Discriminating strata in scatterplots. *J. Amer. Stat. Assoc.*, **84**, 682–688, doi:10.1080/01621459.1989.10478821.

——, M. L. Kalish, and S. Ngang, 2002: Simplified learning in complex situations: Knowledge partitioning in function learning. *J. Exp. Psychol. Gen.*, **131**, 163–193, doi:10.1037/0096-3445.131.2.163.

——, J. S. Risbey, M. Smithson, B. R. Newell, and J. Hunter, 2014a: Scientific uncertainty and climate change: Part I. Uncertainty and unabated emissions. *Climatic Change*, **124**, 21–37, doi:10.1007/s10584-014-1082-7.

——, ——, ——, and ——, 2014b: Scientific uncertainty and climate change: Part II. Uncertainty and mitigation. *Climatic Change*, **124**, 39–52, doi:10.1007/s10584-014-1083-6.

——, N. Oreskes, J. S. Risbey, B. R. Newell, and M. Smithson, 2015: Seepage: Climate change denial and its effect on the scientific community. *Global Environ. Change*, **33**, 1–13, doi:10.1016/j.gloenvcha.2015.02.013.

Marotzke, J., and P. M. Forster, 2015: Forcing, feedback and internal variability in global temperature trends. *Nature*, **517**, 565–570, doi:10.1038/nature14117.

Martinson, D., Ed., 1995: *Natural Climate Variability on Decade-to-Century Time Scales*. National Academy Press, 644 pp.

Meehl, G. A., and H. Teng, 2014: CMIP5 multi-model hindcasts for the mid-1970s shift and early 2000s hiatus and predictions for 2016–2035. *Geophys. Res. Lett.*, **41**, 1711–1716, doi:10.1002/2014GL059256.

Merton, R. K., 1942: The normative structure of science. *The Sociology of Science: Theoretical and Empirical Investigations*, N. Storer, Ed., University of Chicago Press, 267–278.

Mooney, C., 2005: *The Republican War on Science.* Basic Books, 376 pp.

Morice, C. P., J. J. Kennedy, N. A. Rayner, and P. D. Jones, 2012: Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set. *J. Geophys. Res.*, **117**, D08101, doi:10.1029/2011JD017187.

Neely, R. R., and Coauthors, 2013: Recent anthropogenic increases in SO_2 from Asia have minimal impact on stratospheric aerosol. *Geophys. Res. Lett.*, **40**, 999–1004, doi:10.1002/grl.50263.

Oreskes, N., and E. M. Conway, 2010: *Merchants of Doubt.* Bloomsbury Publishing, 368 pp.

Otto, A., and Coauthors, 2013: Energy budget constraints on climate response. *Nat. Geosci.*, **6**, 415–416, doi:10.1038/ngeo1836.

Ridley, D. A., and Coauthors, 2014: Total volcanic stratospheric aerosol optical depths and implications for global climate change. *Geophys. Res. Lett.*, **41**, 7763–7769, doi:10.1002/2014GL061541.

Risbey, J. S., 2015: Free and forced climate variations. *Nature*, **517**, 562–563, doi:10.1038/517562a.

——, S. Lewandowsky, C. Langlais, D. P. Monselesan, T. J. O'Kane, and N. Oreskes, 2014: Well-estimated global surface warming in climate projections selected for ENSO phase. *Nat. Climate Change*, **4**, 835–840, doi:10.1038/nclimate2310.

Santer, B. D., and Coauthors, 2011: Separating signal and noise in atmospheric temperature changes: The importance of timescale. *J. Geophys. Res.*, **116**, D22105, doi:10.1029/2011JD016263.

——, and Coauthors, 2014: Volcanic contribution to decadal changes in tropospheric temperature. *Nat. Geosci.*, **7**, 185–189, doi:10.1038/ngeo2098.

Schmidt, G. A., D. T. Shindell, and K. Tsigaridis, 2014: Reconciling warming trends. *Nat. Geosci.*, **7**, 158–160, doi:10.1038/ngeo2105.

Schneider, S. H., and S. Thompson, 1981: Atmospheric CO_2 and climate: Importance of the transient response. *J. Geophys. Res.*, **86**, 3135–3147, doi:10.1029/JC086iC04p03135.

Seneviratne, S. I., M. G. Donat, B. Mueller, and L. V. Alexander, 2014: No pause in the increase of hot temperature extremes. *Nat. Climate Change*, **4**, 161–163, doi:10.1038/nclimate2145.

Sillmann, J., M. G. Donat, J. C. Fyfe, and F. W. Zwiers, 2014: Observed and simulated temperature extremes during the recent warming hiatus. *Environ. Res. Lett.*, **9**, 064023, doi:10.1088/1748-9326/9/6/064023.

Sloan, T., and A. W. Wolfendale, 2013: Cosmic rays, solar activity and the climate. *Environ. Res. Lett.*, **8**, 045022, doi:10.1088/1748-9326/8/4/045022.

Solomon, S., J. S. Daniel, R. R. Neely, J.-P. Vernier, E. G. Dutton, and L. W. Thomason, 2011: The persistently variable "background" stratospheric aerosol layer and global climate change. *Science*, **333**, 866–870, doi:10.1126/science.1206027.

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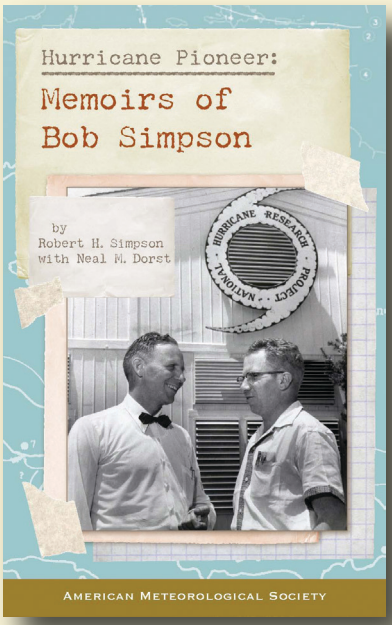

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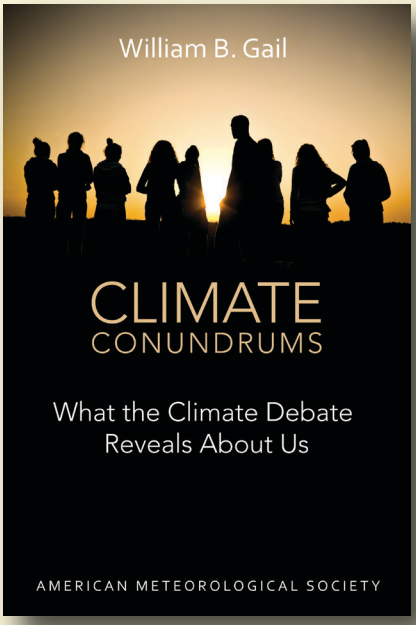

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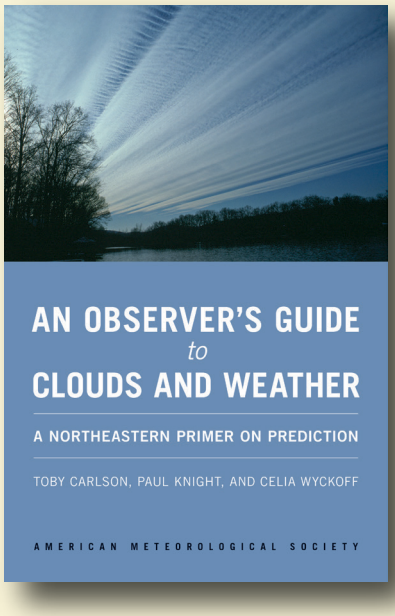

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